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14. ABSTRACT
Describes procedures for evaluating the operational performance of optical-mechanical sighting systems used by towed and self-propelled artillery weapon systems for laying the major armament. Includes boresight procedures and effects of shock, vibration and environmental conditions on sighting system performance.

15. SUBJECT TERMS
Artillery Self-Propelled Artillery Field Artillery Sighting Systems Fire Control Sights Towed Artillery
Boresight Panoramic Telescope Indirect Fire

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 03-2-709 19 November 2010
DTIC AD No.

FIELD ARTILLERY FIRE CONTROL SIGHTS

*This TOP supersedes TOP 03-2-709 Field Artillery Fire Control Sights, dated 14 December 1987

1. SCOPE.

This Test Operations Procedure (TOP) prescribes procedures for evaluating the operational performance of optical-mechanical sighting systems used for laying the major armament of towed and self-propelled artillery; and the effect of shock, vibration, and environmental conditions on sighting system performance. Parameters are as follows:

a. Direct and indirect-fire sighting systems are covered.

b. Boresighting, static shop tests as well as dynamic firing and mobility tests are included.

c. Simulated climatic environmental tests are included (not environmental test at climatic tests sites).

d. The optical quality of the sights is not part of these tests.

The optical-mechanical types of sighting systems for towed and self-propelled artillery are used by the gunner to lay the major armament during direct or indirect-fire missions. The combat effectiveness of field artillery depends on the accuracy, repeatability, and integrity of its sighting and related weapon-laying systems and how well they are secured to the firing platform. These systems include such items as direct and indirect-fire telescopes, elevation quadrants, and related mounts.

The operational testing of these sighting systems consists of subjecting them to road travel vibrations and firing shocks under various test conditions. Then, at specified intervals, the systems are checked for loss of boresight, looseness of parts, misalignment, damage, malfunctioning, and similar effects.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Mechanical Jacks	Sufficient capacity for applicable weapon
Aiming Posts	Two per weapon
Boresight Test Targets	Printed on paper for boresighting
Temperature Chamber	Large enough to house entire howitzer and capable of temperature-conditioning it to -46 °C and +49 °C (-50 °F and +120 °F respectively)
Artillery Firing Range	Large enough to contain the surface danger zone for direct and indirect fire test phases

Item (Continued)	Requirement (Continued)
Rain Test Chamber	Reference 1, Appendix E
Humidity Test Chamber	Reference 1, Appendix E
Solar Radiation Test Chamber	Reference 1, Appendix E
Mobility Test Courses	Reference 2, Appendix E

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty(see NOTE 1)
Gun Tube Quadrant Elevation	0.4 mil
Temperature Inside Climatic Chamber	± 2 °C (± 3.6 °F)
Projectile velocity	0.1%
Gun Tube Azimuth	20 arc seconds

NOTE 1. The permissible error or measurement for instrumentation is the two-sigma value for normal distribution. Thus, stated errors should not be exceeded in more than one measurement of 20.

3. REQUIRED TEST CONDITIONS.

3.1 Item Inspection and Preparation.

a. Before the test is conducted, inspect and service the test platform (i.e., the towed or self-propelled weapon designated to support the test item) in accordance with established procedures. Ordinarily, the tactical weapon, for which the fire control equipment is intended, serves as the test platform. The original mounting of the sights to the test platform should be performed by qualified personnel.

b. Particular attention should be given to the cleanliness of all mounting surfaces.

c. The sighting systems covered by this test procedure normally consist of the following components:

(1) Panoramic telescope (pantel) and mount (indirect fire).

(2) Direct fire telescope and mount (direct fire).

(3) Elevation quadrant.

(4) Cant corrector.

(5) Alignment device.

d. The following information should be recorded before conducting the actual tests:

(1) Evidence of damage to any component during transit.

(2) Condition of exterior surfaces of optics, mating parts, etc.

(3) Misalignment of components.

(4) Any interference between the various components when the weapon is laid at specified elevations, traverse, and vehicle cant.

(5) Ease of mounting fire control sights onto howitzer brackets.

(6) Positive security of sights in their respective mounts.

(7) Adequacy of protective covers and sight storage facilities.

3.2 Boresighting.

Before conducting any of the tests on the fire control equipment, the fire control equipment lines-of-sight (pantel and direct fire telescope) must be aligned with the gun tube centerline (boresighting). Prior to boresighting, the weapon trunnions must be leveled (zero cant). The recommended leveling & boresight procedure is as follows:

a. Place the vehicle (carriage) on a hard, relatively level surface.

b. For self-propelled weapons, place three mechanical jacks beneath the vehicle in accordance with the procedures in the appropriate technical manuals. For towed weapons, spread the trails (if applicable) and place one jack each beneath the undercarriage, left and right. Adjust the jacks to take the full weight of the vehicle (Figure 1).

Figure 1. M109A6 Howitzer with Leveling Jacks.

c. Place/attach string crosshairs on muzzle end of tube to form muzzle crosshair. Most gun tubes will have provisions (witness marks or holes) to help ensure cross hairs are centered. Place boresight disk on breech, see Figure 2.

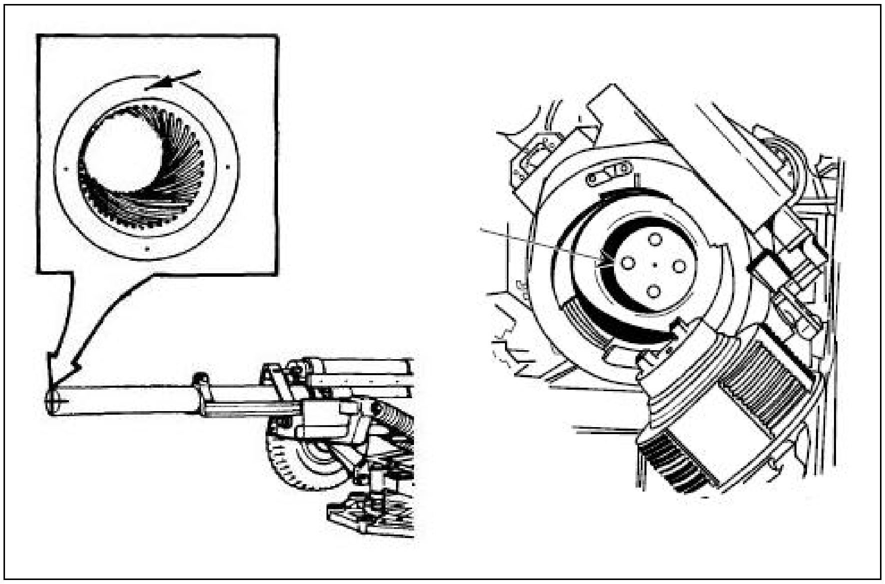


Figure 2. Muzzle Crosshair and Breech Boresight Disk.

d. Suspend a 0.16-cm-diameter (1/16-in.) plumb line no more than 1 meter from the muzzle. This is best done indoors (no wind), with the plumb bob immersed in oil as a precaution to dampen any vibrations (see Figure 3).

Figure 3. Plumb Line Immersed in Oil.

e. While sighting through the boresight disk, traverse the weapon until the center of the boresight disk pinhole and the muzzle crosshairs align with the vertical plumb line.

f. While sighting through the breech boresight disk, and using the center of the muzzle crosshairs as a reference, track the plumb line through at least 800 mils elevation (45°). Make appropriate adjustments to the leveling jacks to render the trunnion axis horizontal (zero cant).

g. Once weapon trunnions are level, level the tube lengthwise by performing an end-for-end check with a gunner's quadrant.

h. Acquire or construct a boresight test target. If test target needs to be fabricated, the material used for its construction should be non-warping and non-shrinking. A typical test target is shown in Figure 4.

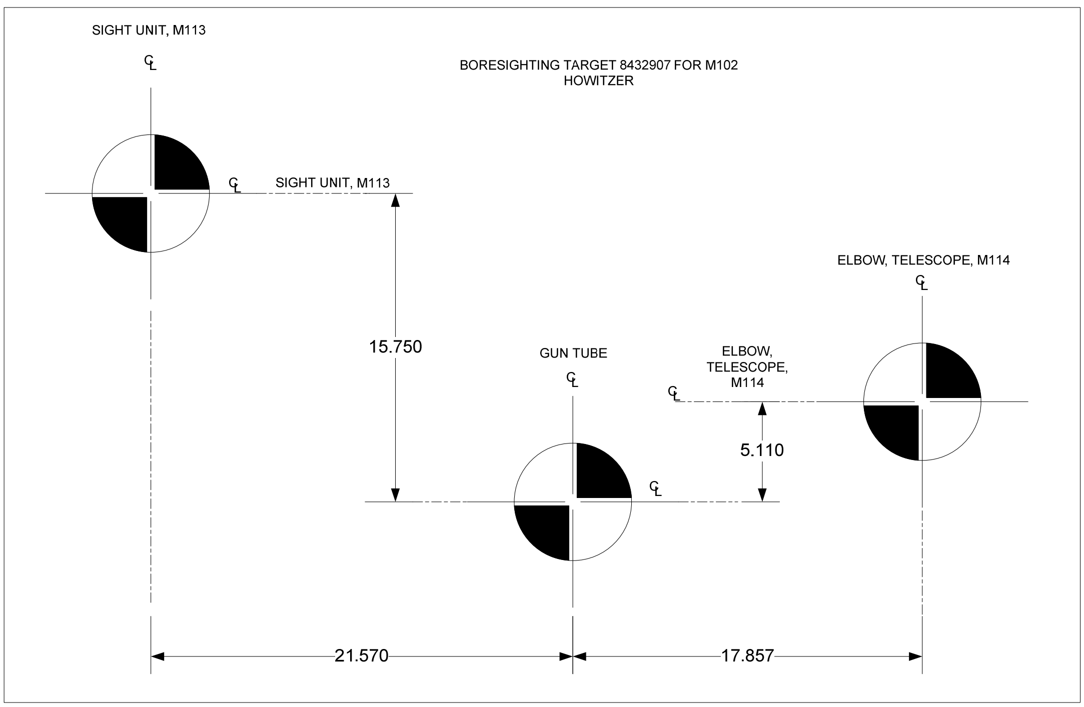


Figure 4. Boresight Test Target.

i. Level telescopes by centering all bubbles (without moving the weapon tube).

j. Adjust all indices, scales, counters, and dials to the proper reading for the weapon tube attitude; for most indicators, this will be zero. An exception is the 6,400 mil azimuth counter which should read exactly 3,200 mils.

k. Set the boresight test target on a wall or stand at least 50 meters away from the weapon muzzle.

l. Adjust the plane of the boresight test target so that it is normal (perpendicular) to the longitudinal axis of the gun tube.

m. Adjust the boresight test target so that the gun tube center line (boresight disk pinhole and muzzle crosshairs) is aligned and level with its corresponding reference circle on the boresight test target (Figure 4 shows gun tube reference circle).

n. Without moving the gun tube, adjust the direct and indirect fire telescope so that their crosshair intersections coincide with the corresponding reference circles on the boresight test target (Figure 5). The azimuth counter should read 3,200 mils ± .5 mils. If not, refer to applicable technical manual or design document for instructions on how to bring reticle into alignment (i.e. remove screws holding cover to gain access to slotted eccentric).

Figure 5. Boresight Test Target Viewed Through Pantel.

4. TEST PROCEDURES.

4.1 Shop Tests.

Shop tests are performed to check all components of the on-carriage fire control systems for Elevation Synchronization, Knob Efforts, Shake, Knob Backlash, Boresight Retention, Walk-Off and Night Performance. Shop tests are performed following the proper mounting of the sighting components before the dynamic testing phases and are repeated at specified intervals to determine whether the systems have satisfactorily withstood exposure to the various test environments.

4.1.1 Elevation Synchronization.

Elevation Synchronization is defined as the angular difference between the gun tube elevation and the elevation counter reading. The recommended procedure to establish Elevation Synchronization is as follows:

a. Elevate/depress gun tube until elevation counter reads 0 mils.

b. Place the calibrated gunner's quadrant on the breech ring elevation pads and measure the breech elevation. Record gunner's quadrant reading.

c. Place calibrated gunners quadrant on muzzle elevation pads and measure muzzle elevation. Record gunner's quadrant reading.

d. Repeat steps "a" through "c", each time elevating gun tube in 200 mil increments as displayed in the elevation counter until max elevation is reached.

e. Repeat procedure (steps "a" through "d") while depressing the gun tube to each of the lower quadrant elevations.

4.1.2 Knob Efforts.

Measure the torque of all adjustment knobs in clockwise and counter-clockwise directions. This should be done using a calibrated torque wrench with a suitable knob adaptor capable of measuring torque in inch-pounds.

4.1.3 Shake.

Shake is defined as the relative displacement of the pantel crosshairs when eyepiece is manually moved. Shake is determined as follows:

a. Select a Distant Aim Point (DAP) that is at least 2,000 meters away.

b. Elevate/depress gun tube to zero degree elevation and lay tube so that the pantel's vertical crosshair is on the DAP.

c. Apply a gradual steady horizontal pull to the eyepiece of the pantel and gradually release the pressure.

d. While sighting through the telescope, determine the magnitude of the horizontal displacement of the vertical crosshair from the DAP. Record the displacement.

e. Repeat steps "c" through "d" by pulling eyepiece in opposite direction. Record the displacement.

f. Repeat steps "b" through "e" at elevation of 800 and 1200 mils.

4.1.4 Backlash.

There are two backlash variables that should be quantified. The first is deflection backlash and is defined as the difference in azimuth counter readings when the pantel's vertical crosshair is brought onto a fixed aim point first from one direction then from the opposite direction. The second is elevation knob backlash and is defined as the difference in elevation counter readings when the pantel's horizontal crosshair is brought onto a fixed aim point first from one direction then from the opposite direction. The following is a recommended procedure to measure backlash:

a. Select a DAP that is at least 2,000 meters away.

b. Lay the gun tube so that pantel's crosshair is on the DAP and gun tube elevation is at zero. Record azimuth counter reading.

c. Turn the Azimuth deflection hand wheel or knob such that the pantel vertical crosshair moves to the right of the distant aim point. Turn knob in opposite direction to center vertical crosshair back onto DAP. Record azimuth counter reading. This is right-left reading.

d. Turn the Azimuth deflection hand wheel or knob such that the pantel vertical crosshair moves to the left of the distant aim point. Turn knob in opposite direction to center vertical crosshair back onto DAP. Record azimuth counter reading. This is left-right reading.

e. The difference between the two azimuth readings (right-left and left-right) is the deflection backlash.

f. Turn the elevation hand wheel or knob such that the pantel's horizontal crosshair moves above the DAP then back onto DAP. Record azimuth counter reading. This is up-down reading.

g. Turn the elevation hand wheel or knob such that the pantel's horizontal crosshair moves below the DAP then back onto DAP. Record azimuth counter reading. This is down-up reading.

h. The difference between the two elevation readings (up-down and down-up) is the elevation knob backlash.

i. Repeat step "b" through "h" for gun tube elevations of 800 and 1,200 mils.

4.1.5 Boresight Retention and Walk-Off.

Boresight retention is defined as the fire control sighting system's ability to stay aligned with gun tube axis. Walk-Off is defined as the angular shift between the pantel's vertical crosshair and gun tube centerline as tube elevation increases.

a. Perform steps "a" through "m" of paragraph 3.2.

b. Sighting through the direct fire telescope and pantel, in turn, determine the amount (in mils) of shift in lines of sight (right or left, up or down) from their respective boresight test target reference circles.

c. Elevate the gun tube from zero to maximum elevation.

d. Re-level the pantel mount and determine the amount (in mils) that the vertical reticle line has moved from its corresponding reference circle on boresight test target. Record angular shift and the direction of shift (left or right).

4.1.6 Night Performance.

Night Performance checks will provide data on ease of use and illumination during night operations. Perform this test at night, preferably in an isolated area, to minimize light pollution. Have the gun crew perform the functions necessary to lay the main armament (use illuminated aiming posts and/or aiming circle).

4.2 Mobility Tests.

Mobility test are performed to evaluate the sighting systems ability to withstand typical travel conditions.

a. Boresight weapon IAW paragraph 3.2.

b. Conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

c. Prepare the weapon for mobility testing (march order) in accordance with applicable technical manual (i.e., sights positively secured on their respective mounts, approved coverings, tube travel position, etc.)

d. Subject test vehicle to at least 134 km (83 mi) of mobility courses as shown in Table 1. Course details can be found in TOP 01-1-011.

Table 1. Mobility Test Schedule.

Course	Distance km (mi)
Washboard, 6 inch	1.6 (1.0)
Paved Road	32.2 (20.0)
Washboard, Radial	1.6 (1.0)
Three-Inch Spaced Bump	1.6 (1.0)
Cross-Country Course No.1	32.2 (20.0)
Gravel Connecting Roads	64.4 (40.0)
Total Distance:	134 km (83 mi)
Notes: Speed for all courses is 16 kilometers/hour (10 miles/hour) Legend: km – kilometer mi – mile No. – number	

e. Conduct shop tests described in paragraphs 4.1.1 through 4.1.6 at conclusion of mobility tests.

4.3 Firing Tests.

Firing tests are conducted to verify the accuracy, ruggedness and repeatability of the various sighting system components when they are subjected to firing shocks at normal temperature conditions. Additionally, this test will verify the ability of the sighting systems to consistently and accurately lay the major armament.

4.3.1 Direct Fire.

a. Boresight weapon IAW paragraph 3.2 and conduct shop tests IAW paragraph 4.1.1 through 4.1.6.

b. Ammunition used for this test shall be temperature-conditioned to 21 °C ± 2 °C (70 °F ± 3.6 °F) for a minimum of 24 hours prior to firing. Surface winds shall be no greater than 5 meters per second (9.7 knots).

c. Select a firing range such that the firing point provides a level surface for weapon emplacement and the difference in elevation between weapon and target is less than 25 meters.

d. Ten rounds will be used for this test, the first 5 should be fired with the highest allowable propelling charge and the second 5 should be fired with the minimum allowable propelling charge for the selected weapon-projectile combination. Inert projectiles should be used for this test.

e. Set up a 6.1 meter by 6.1 meter vertical target at a range of 1,000 meters ± 50 meters from the weapon muzzle. Target should be constructed of wood, tarp or any other material that will easily register the round impacts. Draw a 4.6 meter by 2.3 meter box on center of target as shown in Figure 6.

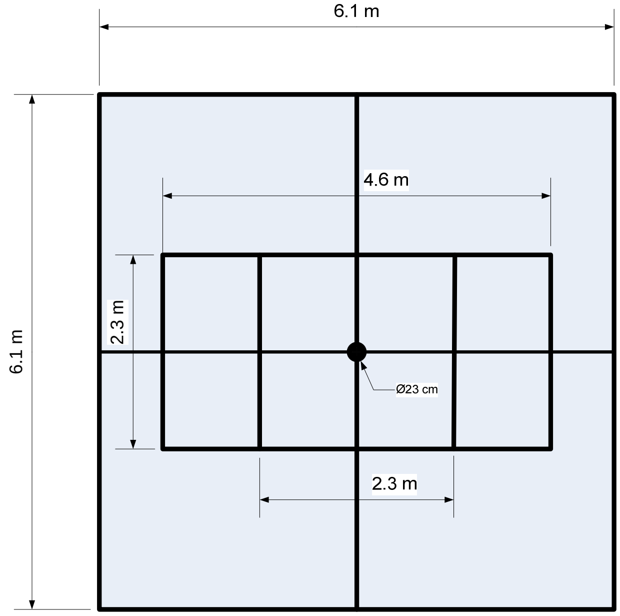
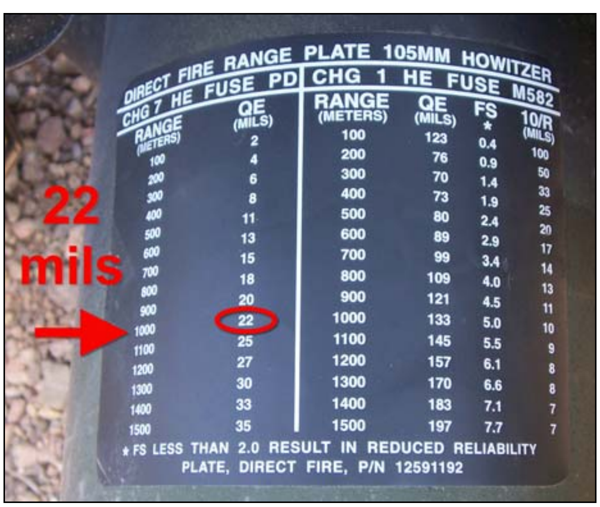


Figure 6. Direct Fire Target.

f. Aim weapon at the target's center impact point using direct fire telescope and apply super elevation as specified in the weapon's direct fire plate. Check weapon elevation using calibrated gunners quadrant. See Figure 7.



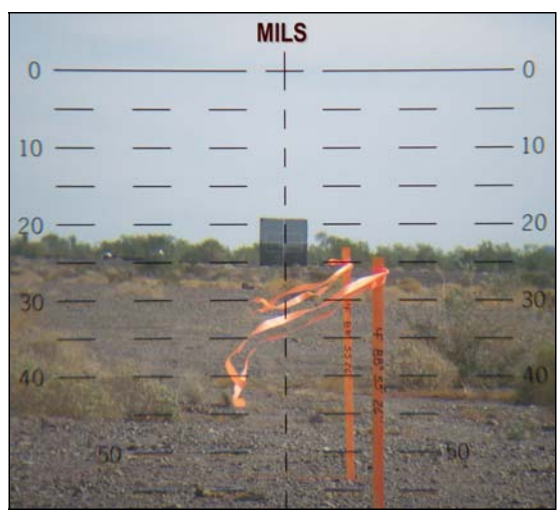


Figure 7. Sample Direct-Fire Plate and View From Direct-Fire Telescope.

g. Fire a spotter round (propelling charge is same as that for first 5-round group) at the target to ensure weapon is properly aligned. Observers or video cameras should be used to capture the projectile trajectory in the event of a miss. If it misses, attempt to estimate the amount and direction of miss then adjust the weapon accordingly prior to firing a second spotter round. Repeat process until a hit inside the 2.3 meter by 2.3 meter rectangle is registered.

h. Identify the spotter holes on the target with paint or marker on a video screen.

i. Fire the first 5-round group at the target and identify the holes belonging to this 5-round group with paint or marker on a video screen. Check the direct fire telescope to make sure it is still centered on target after every round.

j. Prepare to fire the second 5-round group by firing spotter rounds at the target.

k. Identify the holes belonging to this group of spotters.

l. Fire the second 5-round group at the target and identify the holes with paint or marker on a video screen. Check the direct fire telescope to make sure it is still centered on target after every round.

m. For each hole (test rounds only), measure the horizontal and vertical distance from center aim point.

n. Conduct shop tests described in paragraphs 4.1.1 through 4.1.6 at conclusion of direct fire test.

4.3.2 Indirect Fire.

a. Boresight weapon IAW paragraph 3.2 and conduct shop tests IAW paragraph 4.1.1 through 4.1.6.

b. Conduct the indirect-fire phase with the highest allowable propelling charge for the selected weapon-projectile combination. All ammunition should be temperature-conditioned to 21 °C (70 °F) for 24 hours prior to firing.

c. Select a firing range (gun position and impact area) such that the firing point provides a level surface for weapon emplacement. Establish a weapon line-of-fire that will yield projectile impacts in a safe and acceptable location.

d. At the Gun Position, place a stake marking the location of the weapon pantel. Place and survey the Behind-the-Gun (BG) Theodolite approximately 15 meters behind the weapon along the rearward extension of the line of fire as shown in Figure 8.

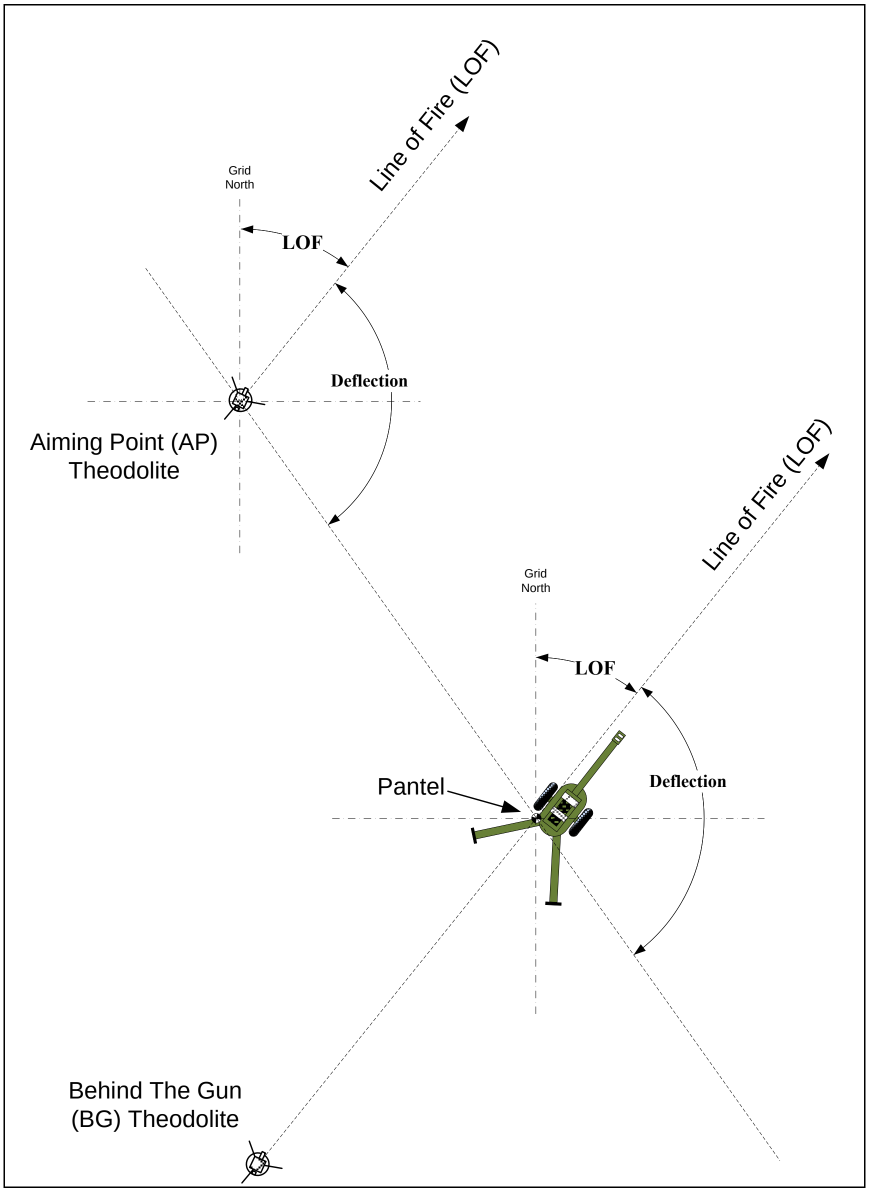


Figure 8. Firing Point Survey.

e. Place and survey the Aiming Point (AP) Theodolite or aiming circle to the left of the weapon approximately 15 meters away. Zero the AP Theodolite such that its 0 mil graduation coincides with the LOF then measure and record the initial deflection as shown in Figure 8.

f. Set the pantel to the initial deflection obtained in previous step. Lay weapon such that the tube is oriented in general direction of fire and the pantel is close to the pantel marking stake.

g. Once weapon is emplaced, traverse the gun tube until the pantel's reticle is on the AP Theodolite lens.

h. Using the AP Theodolite re-measure the deflection of the weapon's pantel as shown in Figure 8.

i. Set the pantel to the newly measured deflection. Traverse the gun tube until the pantel reticle is on the AP Theodolite lens.

j. Repeat steps h and i until the deflection measured by the AP Theodolite is the same as the deflection on the pantel counter.

NOTE 2: The procedures outlined in steps d through j for laying the weapon are IAW reciprocal laying techniques of reference 3 of appendix E.

k. Measure the trunnion cant using a gunners quadrant. Compute the Theodolite correction angle (Φ) using equation 24 or 25 of Appendix D.

l. Measure the gun tube LOF using BG Theodolite. Compare the Theodolite LOF (corrected for cant Φ) with the LOF reported by the pantel. If they differ by more than 1 mil, note the difference and use BG Theodolite LOF to fire the weapon.

m. Fire a total of 30 test rounds for this test (two, 15-round groups). Inert projectiles are preferred but not necessary. Table 2 outlines the firing schedule for this phase.

Table 2. Indirect Fire Matrix.

Test Group[2]	**Test Round No.**	**Weapon Quadrant Elevation**[1] **(mils)**
1	1-15	750-850
2	16-30	1200-1300
Notes: 1) Use calibrated gunners quadrant to set weapon elevations 2) Fire spotter/warmer rounds as required		

n. After every round fired, check the weapon LOF with the BG Theodolite. Adjust weapon as necessary to keep tube on line of fire. If weapon is adjusted, record the pantel azimuth reading.

o. After the first 15-round group, move the weapon from the firing point and re-lay it by following steps "e" through "i".

p. Conduct shop tests described in paragraphs 4.1.1 through 4.1.6 at the conclusion of direct fire test.

4.4 Climatic Tests.

Climatic Tests are performed to verify the accuracy, ruggedness, and repeatability of the various sighting system components after exposure to firing shocks at extreme temperatures and the effects of solar radiation, rain, and humidity.

4.4.1 Extreme Temperature Tests.

When possible, conduct extreme temperature tests of the system concurrently with test of the major armament. If this is not feasible, conduct these tests after the indirect-fire phase. Conduct this test with the highest allowable propelling charge for the selected weapon-projectile combination. All ammunition should be temperature-conditioned to the same temperature as the weapon.

a. Ensure weapon is boresighted IAW paragraph 3.1. Conduct shop tests described in paragraphs 4.1.1 through 4.1.6 prior to conducting Extreme Temperature Test.

b. Conduct the following inspections/checks of all on-carriage fire control components:

(1) Knob efforts of all adjustments.

(2) Ease of operation.

(3) Evidence of fogging of optics.

(4) Clearness of reticles.

(5) Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.

(6) Flexibility and effectiveness of eyepiece rubber guards, etc.

(7) Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability, to focus sights, etc.).

(8) Misalignment, damage, or abnormal play between sights and their mounting surfaces.

(9) Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).

(10) Ease of installing and removing sight protective covers; particular attention should be paid to the pliability of the material (i.e., canvas, plastic, rubber, etc.) at low temperatures.

c. Place the weapon inside the climatic chamber, raise the temperature to 49 °C ± 2 °C (120 °F ± 3.6 °F), and let weapon soak for 24 hours.

d. Fire 10 rounds (Hot) IAW Table 3.

e. Allow weapon and climatic chamber temperature to return to ambient conditions then conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

f. Conduct the following inspections/checks of all on-carriage fire control components:

(1) Knob efforts of all adjustments.

(2) Ease of operation.

(3) Evidence of fogging of optics.

(4) Clearness of reticles.

(5) Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.

(6) Flexibility and effectiveness of eyepiece rubber guards, etc.

(7) Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability, to focus sights, etc.).

(8) Misalignment, damage, or abnormal play between sights and their mounting surfaces.

(9) Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).

(10) Ease of installing and removing sight protective covers; pay particular attention to the pliability of the material (i.e., canvas, plastic, rubber, etc.) at low temperatures.

g. Place the weapon inside the climatic chamber, lower the temperature to -46 °C ± 2 °C (-50 °F ± 3.6 °F), and let weapon soak for 24 hours.

h. Fire 10 rounds (Cold) IAW Table 3.

i. Allow weapon and climatic chamber temperature to return to ambient conditions then conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

j. Conduct the following inspections/checks of all on-carriage fire control components:

(1) Knob efforts of all adjustments.

(2) Ease of operation.

(3) Evidence of fogging of optics.

(4) Clearness of reticles.

(5) Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.

(6) Flexibility and effectiveness of eyepiece rubber guards, etc.

(7) Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability, to focus sights, etc.).

(8) Misalignment, damage, or abnormal play between sights and their mounting surfaces.

(9) Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).

(10) Ease of installing and removing sight protective covers; pay particular attention to the pliability of the material (i.e., canvas, plastic, rubber, etc.) at low temperatures.

NOTE: The hot temperature selected for this test is derived from the "Daily High" Operational Conditions for the "Hot-Dry (A1)" Daily Cycle of MIL-STD-810G dated 31 October 2008 (Table C-1). The cold temperature selected for this test is derived from the "Daily Low" Operational Conditions for the "Cold (C2)" Daily cycle of MIL-STD-810G dated 31 October 2008 (Table C-1).

Table 3. Extreme Temperature Firing Matrix.

Extreme Temperature Test[2]	**Temperature**[3]	**Qty**	**Weapon Quadrant Elevation**[1]
Hot	49° C (120° F)	10	750-850
Cold	-46° C (-50° F)	10	750-850

Notes:
1) Use calibrated gunners quadrant to set weapon elevations
2) Fire spotter/warmer rounds s required
3) Temperature tolerance is ± 2 °C

Legend:
Qty – quantity
C – Celsius
F- Fahrenheit

4.4.2 Solar Radiation Test (towed howitzers only).

The fire control sights for towed howitzers will reach much higher temperatures under the desert sun than will the heavier portions of the weapon system. This is due to their exposed positions and their relatively low heat capacity. Conduct the solar radiation test of the fire control sights of towed howitzers to determine the effects solar radiation and high air temperature will have on the seals, adhesives, optical alignment, or other portions of the sights.

a. Remove fire control sights from the weapon (pantel and direct fire telescope).

b. Construct a stand to hold the sights in the same configuration/orientation they mount on weapon.

c. Subject the sights to the solar radiation test method 505.5, Procedure I, Cycle A1 of MIL-STD-810G dated 31 October 2008.

d. After solar radiation test, examine the sights for evidence of sun and heat damage and ease of operation.

e. After exposure, reassemble sights to the weapon Boresight IAW paragraph 3.2 then conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

NOTE: If the fire control sight developer has conducted sufficient solar radiation tests, the test and evaluation agency can opt to eliminate the solar radiation test and use the developer's data for evaluation.

4.4.3 Rain Test (towed howitzers only).

The fire control sights of towed howitzers are exposed, and as such, are subject to rain. In order to ensure the sights do not experience moisture penetration, conduct a rain test.

a. Remove the fire control sights from the weapon (pantel and direct fire telescope).

b. Construct a stand to hold the sights in the same configuration/orientation they mount on the weapon.

c. Subject the sights to the rain test method 506.5, Procedure I, of MIL-STD-810G dated 31 October 2008.

d. After the rain test, examine the sight for evidence of water and moisture penetration and ease of operation.

e. Reassemble sights to the weapon. Boresight IAW paragraph 3.1 and 3.2 then conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

NOTE: If the fire control sight developer has conducted sufficient rain tests, the test and evaluation agency can opt to eliminate the rain test and use the developer's data for evaluation.

4.4.4 Humidity Test.

Fire control sights for both towed and self propelled howitzers are subject to humidity. Conduct this test to ensure the sights do not experience moisture penetration from exposure to high humidity.

a. Remove the fire control sights from the weapon (pantel and direct fire telescope).

b. Construct a stand to hold the sights in the same configuration/orientation they mount on the weapon.

c. Subject the sights to the humidity test method 507.5, Procedure I, Cycle B1 of MIL-STD-810G dated 31 October 2008. Use the Non-Hazardous Items Normal Test Duration.

d. After the humidity test, examine the sight for evidence of moisture penetration, corrosion, expansion, condensation and ease of operation.

e. Reassemble sights to the weapon. Boresight IAW paragraph 3.1 and 3.2 then conduct shop tests described in paragraphs 4.1.1 through 4.1.6.

5. DATA REQUIRED.

Collect all test data in such a manner that the overall accuracy, ruggedness, ease of operation, and adequacy of the sighting systems can be evaluated readily and compared with the pertinent specification or design requirements. Appendix C contains comprehensive examples of the data collection tables each individual test.

6. PRESENTATION OF DATA.

Present all test data in such a manner that the overall accuracy, ruggedness, ease of operation, and adequacy of the sighting systems can be evaluated readily and compared with the pertinent specification or design requirements. Appendix C contains examples of how the data should be presented.

6.1 Sources of Error.

Generally speaking, the errors in a field artillery fire control sighting system can be categorized as follows:

a. Mechanical Errors – Excessive backlash or play, poor workmanship, deformed parts (i.e., gears, linkages, etc.)

b. Optical Errors – Errors attributed to poor quality prisms, lenses, or other optical components; defective components (e.g., reticles); or poor assembly procedures (i.e., nonparallel mounting planes which permit angular deviations of optical centers of sight lines.)

c. Unexplainable Errors – Those errors which cannot be charged to the mechanical or optical systems. For example: human errors, errors resulting from internal/external ballistics, faulty meteorological data, unknown projectiles yaw, etc.

In some cases, the different types of errors can be separated by an analysis of the data obtained. If such errors are suspected, the presentation of data shall indicate where the errors may have occurred. It is assumed that all components of the sighting system meet specification tolerances before their receipt by a developmental test agency which should always have available master telescopes, etc., that are periodically checked by the responsible fire control office.

APPENDIX A. GLOSSARY.

Term	Definition
Backlash	Play or lost motions between fitted machine parts such as gears
Behind-the-Gun	Position located directly behind a weapon system, usually the location of a survey Theodolite
Boresighting	The act of aligning the gun tube centerline with the centerline of the sighting system
Breech	Part of cannon assembly where projectile and propelling charge are inserted, rear end of a cannon assembly
Cant	Angular deflection from the horizontal of the trunnion centerline
Carriage	Bottom part of howitzer which supports the turret and/or recoil mechanism
Direct Fire	Act of firing at a target that is visible (line of sight) from the weapon
Distant Aim Point	A feature (geographical or man-made) that is at least 2000 meters away that can be used as a reference via the pantel
End-for-end check	Checking the elevation using a gunner’s quadrant with it oriented in one direction then reversing its direction and confirming the same elevation
Indirect Fire	Act of firing at a target that is beyond the weapon’s direct line of sight
Major Armament	Large caliber weapon on a howitzer
Muzzle	Part of cannon assembly where projectile exits when if fires
Pantel	Panoramic telescope

APPENDIX A. GLOSSARY.

Sigma	Term for one standard deviation
Super Elevation	Elevation applied to gun tube during direct fire missions
Theodolite	Survey instrument to accurately measure azimuth and elevation
Trunnions	Part of the gun mount at which the gun tube pivots vertically

APPENDIX B. ABBREVIATIONS.

Term	Definition
AP	Aiming Point
BG	Behind-the-Gun
C	Celsius
DAP	Distant Aim Point
F	Fahrenheit
IAW	In accordance with
LOF	Line of fire
TOP	Test operations procedure

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

SHOP TEST DATA

Test Name:	Elevation Synchronization		
Test Sequence:	Initial Shop Tests		
Test Location:	Bldg XXXX		
Date:	dd-mmm-yy		
Weapon Model:	M109A6		
Elevation Counter Reading (mils)	**Gunner's Quadrant Elevation (mils)**		**Elevation Synchronization (mils)**
	Breech	Muzzle	
0			
200			
400			
600			
800			
1000			
1200			
1000			
800			
600			
400			
200			
0			
Remarks/Notes:			

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

Test Name:	Knob Effort	
Test Sequence:	Initial Shop Tests	
Test Location:	Bldg XXXX	
Date:	dd-mmm-yy	
Weapon Model:	M109A6	
Knob	**Clockwise Torque (in-lbs)**	**Counterclockwise Torque (in-lbs)**
Pantel		
Pitch		
Cant		
Azimuth		
Elevation		
Elevation Correction		
Direct Fire Scope		
Cant		
Pitch		
Correction		
Remarks/Notes:		

Test Name:	Shake	
Test Sequence:	Initial Shop Tests	
Test Location:	Bldg XXXX	
Date:	dd-mmm-yy	
Weapon Model:	M109A6	
DAP:	Communication tower, 2000 meters	
Gunner's Quadrant Elevation (mils)	**Deflection (mils)**	
	Right	**Left**
0		
800		
1200		
Remarks/Notes:		

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

Test Name:	Backlash
Test Sequence:	Initial Shop Tests
Test Location:	Bldg XXXX
Date:	dd-mmm-yy
Weapon Model:	M109A6
DAP:	Communication tower, 2000 meters
DAP Azimuth:	3200 mils

Tube Elevation (mils)	**Deflection Backlash**		**Elevation Backlash**	
	Right-Left	**Left-Right**	**Up-Down**	**Down-Up**
0				
800				
1200				
Remarks/Notes:				

Test Name:	Boresight Retention and Walk-Off
Test Sequence:	Initial Shop Tests
Test Location:	Bldg XXXX
Date:	31 Aug-09
Weapon Model:	M109A6
Distance to Boresight Test Target:	60 meters

Tube Elevation (mils)	**Boresight Azimuth Shift (mils/direction)**		**Boresight Elevation Shift (mils)**
	Pantel	**Direct-fire Telescope**	
0			
1250-0			
Remarks/Notes:			

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

Test Name:	Night Performance Test
Test Sequence:	Initial Shop Tests
Test Location:	Bldg XXXX
Date:	dd-mmm-yy
Weapon Model:	M109A6
Item	**Description**
Warning lights	
Light switches	
Range scales	
Level vials	
Azimuth indicators	
Knobs	
Control panels	
Dials	
Other	
Other	
Other	
Adequacy/effectiveness of illumination systems:	
Ability to see illuminated aiming posts and/or aiming circle:	
Remarks/Notes:	

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

MOBILITY TESTS DATA:

1. Results of shop tests before and after mobility testing.

2. Sample Mobility Test Data:

Test Name:	Mobility Testing
Test Sequence:	Mobility Testing
Test Location:	mobility courses
Date:	dd-mmm-yy
Weapon Model:	M109A6
Prime Mover:	Self propelled
Course Name	**Actual Distance Traveled (km)**
Washboard, 6 inch	
Paved Road	
Washboard, Radial	
Three-Inch Spaced Bump	
Cross-Country Course No.1	
Gravel Connecting Roads	
Remarks/Notes:	

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

FIRING TEST - DIRECT FIRE TESTS DATA:

1. Results of shop tests before and after direct fire testing

2. Sample Direct Fire Test round by round data:

Test Name:	Direct Fire						
Test Sequence:	Firing tests						
Date:	dd-mmm-yy						
Weapon Model:	M109A6						
Test Location:	Gun Position						
Gun Position Coordinates:	X:		Y:		Z:		
Target Coordinates:	X:		Y:		Z:		
Round Type	**Propelling Charge (model / zone)**	**Projectile (model)**	**Fuze (model)**	**Super Elevation (mils)**	**Elevation Counter Reading (mils)**	**Horizontal distance from target center (m)**	**Vertical distance from target center (m)**
Spotter	M231 / Z1	M107	M557				
Spotter	M231 / Z1	M107	M557				
Test	M231 / Z1	M107	M557				
Test	M231 / Z1	M107	M557				
Test	M231 / Z1	M107	M557				
Test	M231 / Z1	M107	M557				
Test	M231 / Z1	M107	M557				
Spotter	M232 / Z5	M795	M557				
Test	M232 / Z5	M795	M557				
Test	M232 / Z5	M795	M557				
Test	M232 / Z5	M795	M557				
Test	M232 / Z5	M795	M557				
Test	M232 / Z5	M795	M557				
Remarks/Notes:							

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

FIRING TESTS - INDIRECT FIRE TESTS DATA:

1. Results of shop tests before and after Indirect Fire Testing.

2. Sample Indirect Fire Test round by round data:

Test Name:	Indirect Fire		
Test Sequence:	Firing tests		
Date:	dd-mmm-yy		
Weapon Model:	M109A6		
Test Location:	Gun Position		
Pantel Coordinates:	X:	Y:	Z:
AP Theodolite Coordinates:	X:	Y:	Z:
BG Theodolite Coordinates:	X:	Y:	Z:
Trunnion Cant:	18 mils		
Pantel LOF:	1400 mils	**BG Theodolite LOF:**	1400.5 mils

Round No	**Prop Chg** (model / zone)	**Proj** (model)	**Fuze** (model)	**QE** (mils)	**Theodolite Correction Angle (Φ)** (mils)	**Pantel LOF Adjustment**[1]	**BG Theodolite LOF** (mils)	**Corrected BG Theodolite LOF** (mils)
1	M232 / Z5	M549A1	M557	800				
2	M232 / Z5	M549A1	M557	800				
3	M232 / Z5	M549A1	M557	800				
4	M232 / Z5	M549A1	M557	800				
5	M232 / Z5	M549A1	M557	800				
6	M232 / Z5	M549A1	M557	1200				
7	M232 / Z5	M549A1	M557	1200				
8	M232 / Z5	M549A1	M557	1200				
9	M232 / Z5	M549A1	M557	1200				
10	M232 / Z5	M549A1	M557	1200				
Remarks/Notes:								

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

CLIMATIC TESTS - EXTREME TEMPERATURE TEST DATA:

1. Results of shop tests before Extreme Temperature Test – Hot.

2. Sample Extreme Temperature Test data:

Test Name:	Extreme Temperature Test - Hot		
Test Sequence:	Climatic Tests		
Date:	dd-mmm-yy		
Weapon Model:	M109A6		
Test Location:	Gun Position		
Center of Trunnion Coordinates:	X:	Y:	Z:

Inspection Checks	**Result**
Knob efforts of all adjustments	
Ease of operation	
Evidence of fogging of optics	
Clearness of reticles	
Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.	
Flexibility and effectiveness of eyepiece rubber guards, etc.	
Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability, to focus sights, etc.)	
Misalignment, damage, or abnormal play between sights and their mounting surfaces.	
Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).	
Ease of installing and removing sight protective covers (pliability of canvas, plastic, rubber, etc. at low temperatures).	

Round group	**Propelling Charge (model / zone)**	**Projectile (model)**	**Fuze (model)**	**QE (mils)**	**LOF (mils)**	**Comments**
Hot (120° F)	M232 / Z5	M549A1	M557			

Remarks/Notes:

Legend:
LOF – line of fire
QE – quadrant elevation

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

1. Results of shop tests before Extreme Temperature Test – Cold.

2. Sample Extreme Temperature Test data:

Test Name:	Extreme Temperature Test - Cold					
Test Sequence:	Climatic Tests					
Date:	dd-mmm-yy					
Weapon Model:	M109A6					
Test Location:	Gun Position					
Center of Trunnion Coordinates:	X:	Y:	Z:			
Inspection Checks	**Result**					
Knob efforts of all adjustments						
Ease of operation						
Evidence of fogging of optics						
Clearness of reticles						
Adequacy and dependability of illumination for dials, vials, counter windows, reticles, etc.						
Flexibility and effectiveness of eyepiece rubber guards, etc.						
Evidence of any failure of optical sights (i.e., failure of bonding cements for prisms, inability, to focus sights, etc.)						
Misalignment, damage, or abnormal play between sights and their mounting surfaces.						
Any failure of leveling vials (i.e., loss of bubble, glass fracture, etc.).						
Ease of installing and removing sight protective covers (pliability of canvas, plastic, rubber, etc. at low temperatures).						

Round group	**Propelling Charge (model / zone)**	**Projectile (model)**	**Fuze (model)**	**QE (mils)**	**LOF (mils)**	**Comments**
Cold (-50° F)	M232 / Z5	M549A1	M557			
Remarks/Notes: Legend: LOF – line of fire QE – quadrant elevation						

APPENDIX C. SAMPLE DATA COLLECTION TABLES.

1. Results of shop tests after Extreme Temperature Test – Cold.

CLIMATIC TESTS – SOLAR RADIATION TEST DATA:

1. Results of shop tests before and after Solar Radiation Testing.

2. Photographs and description of stand used to hold sights inside radiation chamber.

3. Description and/or photographs of any damage or evidence of sun damage.

CLIMATIC TESTS – RAIN TEST DATA:

1. Results of shop tests before and after Rain Testing.

2. Photographs and description of stand used to hold sights inside rain facility.

3. Description and/or photographs of any damage or evidence of moisture penetration.

CLIMATIC TESTS – HUMIDITY TEST DATA:

1. Results of shop tests before and after Humidity Testing.

2. Photographs and description of stand used to hold sights inside humidity chamber.

3. Description and/or photographs of any damage or evidence of moisture penetration.

APPENDIX D. THEODOLITE CORRECTION ANGLE.

When aligning a gun tube using a Theodolite, a line is drawn on the outer surface of the gun tube such that it represents the gun tube centerline (the line and the tube centerline prescribe a vertical plane). The Theodolite vertical reticle can then be used to line up the gun tube using the prescribed line. When the weapon trunnion is in a horizontal plane (zero cant) and the gun tube is not tapered, the prescribed line drawn on the outer surface of the tube coincides with the true azimuth of the gun tube.

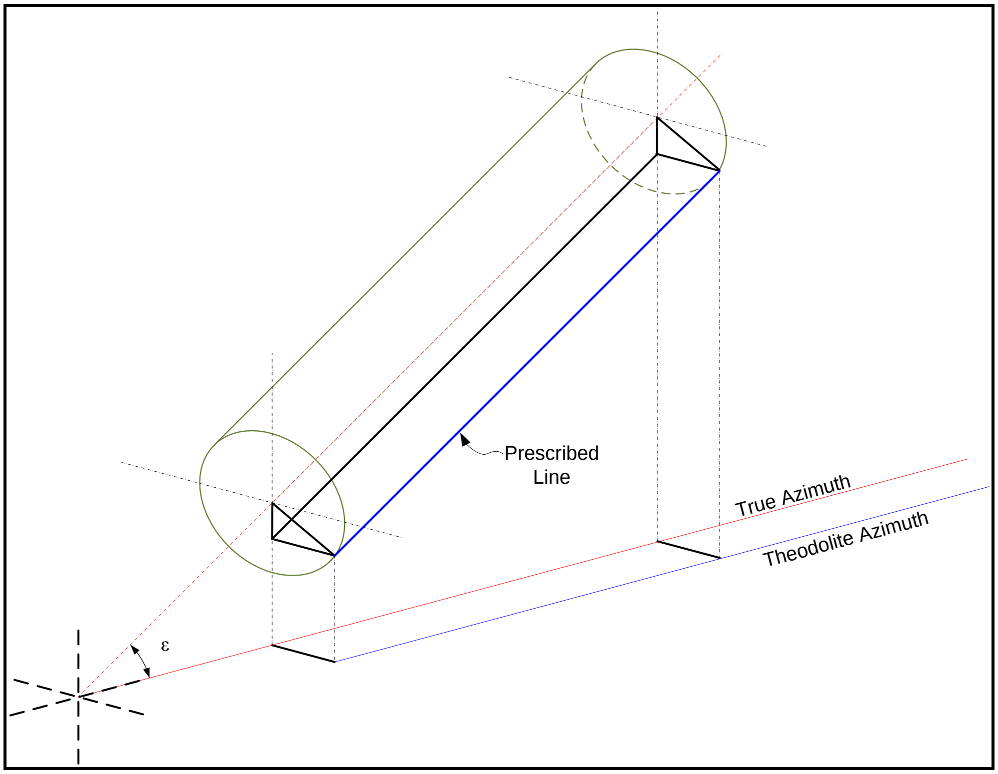


Figure D-1. Gun Tube Azimuth with Zero Cant and No Tube Taper.

However, if the trunnion is canted and/or the tube is tapered, the azimuth of the prescribed line will not coincide with the true azimuth of the gun tube. In this case, the vertical plane containing the prescribed line (shown in blue, Figure D-2) is not parallel with the vertical plane containing the axis of the tube (shown in red, Figure D-2).

APPENDIX D. THEODOLITE CORRECTION ANGLE.

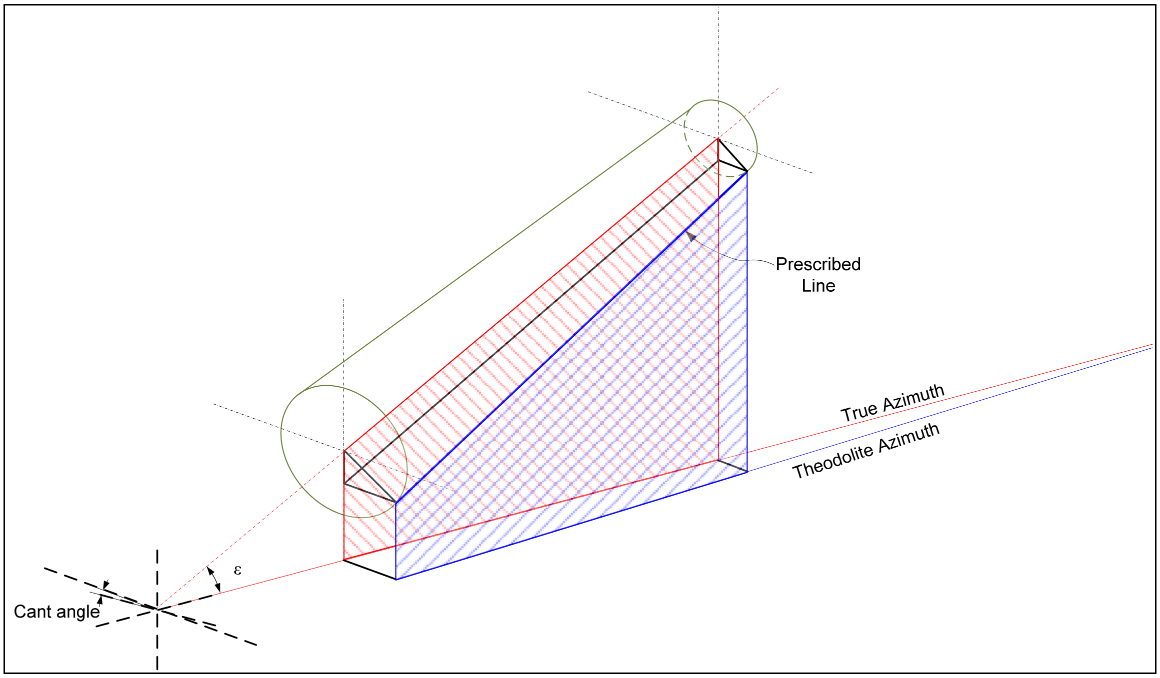


Figure D-2. Gun Tube Azimuth with Cant and Tube Taper.

The size of the smaller dihedral angle formed by these two vertical planes is the Theodolite Correction Angle (Φ) and represents the amount by which the prescribed line azimuth differs from the true azimuth of the gun tube. The azimuth of the prescribed line, as measured by a Theodolite, can be corrected using Φ to give the true azimuth of the tube. The corrected Theodolite azimuth can then in turn be compared to the azimuth reported by the fire control system.

APPENDIX D. THEODOLITE CORRECTION ANGLE.

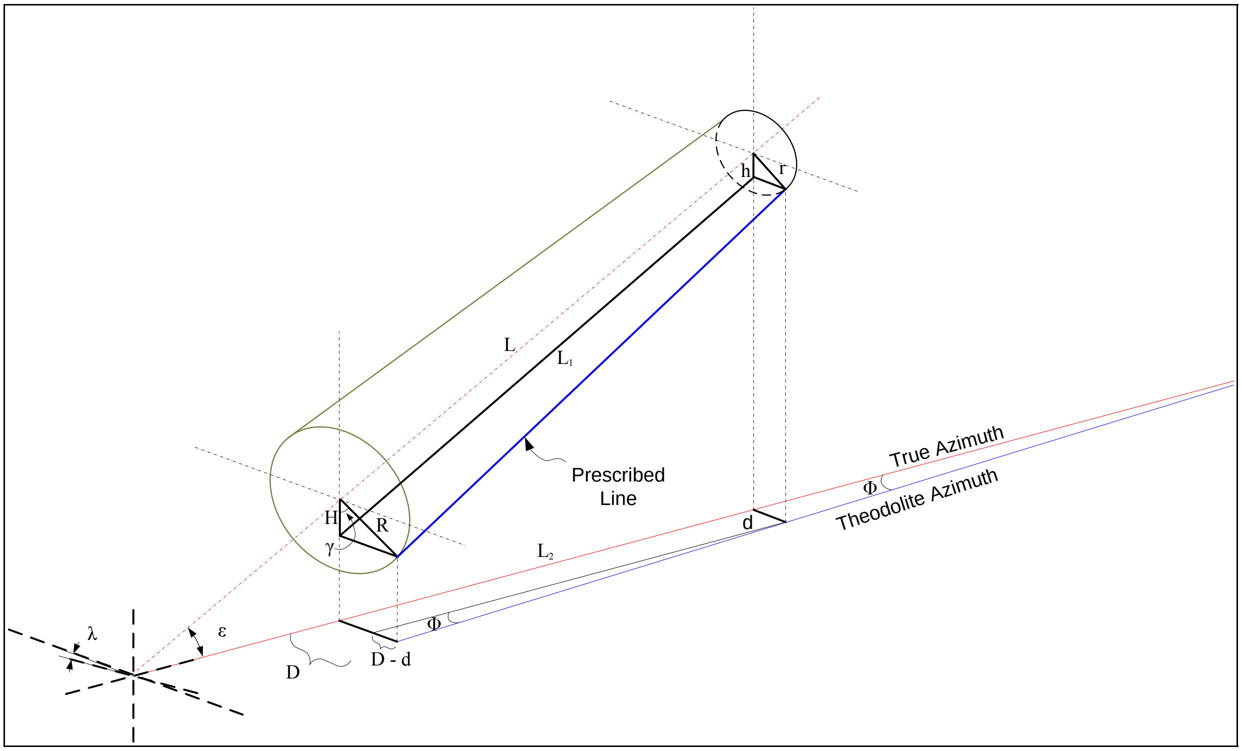


Figure D-3. Theodolite Correction Azimuth.

The magnitude of Φ depends upon the taper of the tube, the trunnion cant magnitude (λ) and the elevation of the tube (ε). For a given tube with known taper, the magnitude of Φ can be determined for various combinations of cant and elevation. The derivation of the equation for calculating Φ is as follows:

From Figure 3:

$$Tan(\Phi) = \frac{D-d}{L_2} \tag{1}$$

From Figure D-3:

$$D = R \cdot Sin(\gamma) \tag{2}$$

$$d = r \cdot Sin(\gamma) \tag{3}$$

Then:

$$D-d = (R-r) \cdot Sin(\gamma) \tag{4}$$

Substituting equation (4) into equation (1) gives:

$$Tan(\Phi) = \frac{(R-r) \cdot Sin(\gamma)}{L_2} \tag{5}$$

APPENDIX D. THEODOLITE CORRECTION ANGLE.

Variables from Figure D-3:

R – radius of gun tube at large end
r – radius of gun tube at small end
λ - cant angle
L - length of the orthogonal projection of the scribed line on the axis of the tube
γ - plane angle of the dihedral angle formed by the vertical plane containing the axis of the tube and the plane in which the tube is actually elevated

By looking at a side view of the tube, L_2 can be calculated:

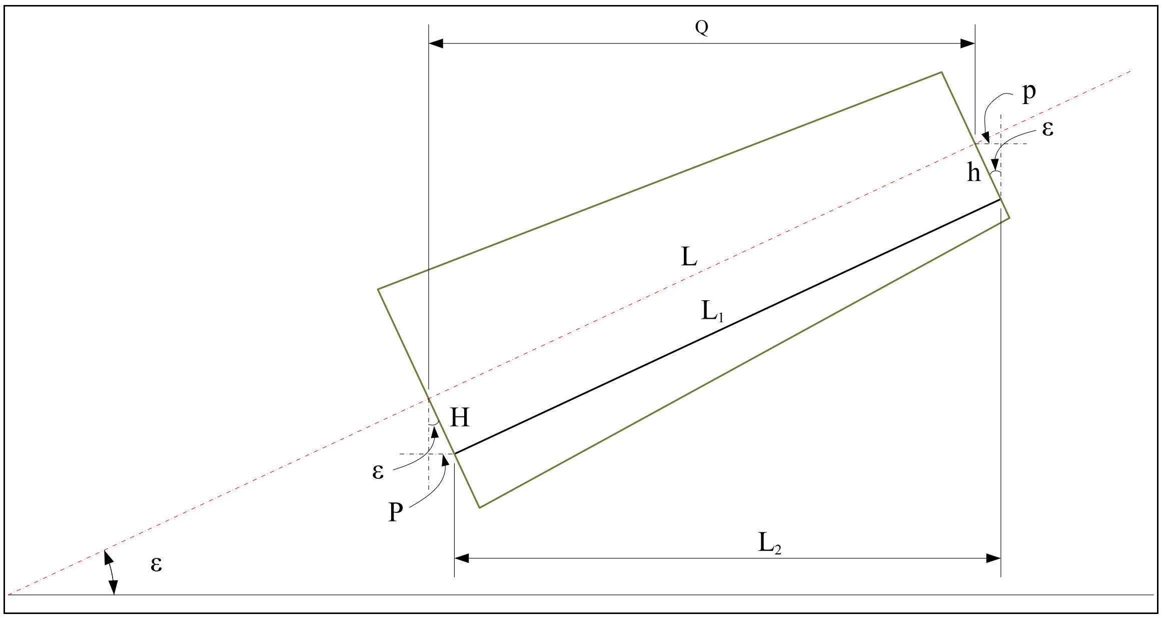


Figure D-4. Side View of Gun Tube.

From Figure D-4:

$$L_2 = Q + P - p \tag{6}$$

Since:

$$P = H \cdot Sin(\varepsilon) \tag{7}$$

$$p = h \cdot Sin(\varepsilon) \tag{8}$$

$$Q = L \cdot Cos(\varepsilon) \tag{9}$$

Substituting equation (7), (8) and (9) into equation (6) gives:

$$L_2 = L \cdot Cos(\varepsilon) + H \cdot Sin(\varepsilon) - h \cdot Sin(\varepsilon) \tag{10}$$

APPENDIX D. THEODOLITE CORRECTION ANGLE.

Since:

$$H = R \cdot Cos(\gamma) \tag{11}$$

$$h = r \cdot Cos(\gamma) \tag{12}$$

Substituting equation (11) and (12) into equation (10) gives:

$$L_2 = L \cdot Cos(\varepsilon) + R \cdot Cos(\gamma) \cdot Sin(\varepsilon) - r \cdot Cos(\gamma) \cdot Sin(\varepsilon) \tag{13}$$

Simplifying equation 13 gives:

$$L_2 = L \cdot Cos(\varepsilon) + (R - r) \cdot Cos(\gamma) \cdot Sin(\varepsilon) \tag{14}$$

To find Sin(λ), a 3-dimensional representation of the vertical plane containing the axis of the tube and the plane in which the tube is actually elevated is required. This is illustrated in Figure D-5.

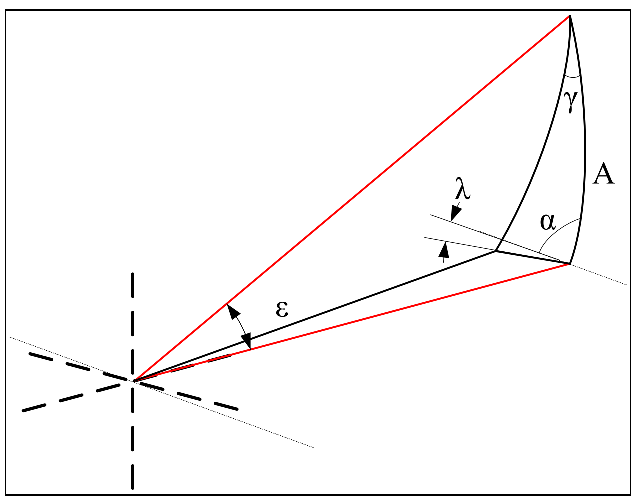


Figure D-5. 3-Dimensional View of planes.

From Figure D-5:

$$Sin(\gamma) = \frac{Cos(\alpha)}{Cos(A)} \tag{15}$$

Since:

$$\alpha = 90^o - \lambda \tag{16}$$

$$Arc\ A = \varepsilon \quad \text{(small angle approximation)} \tag{17}$$

APPENDIX D. THEODOLITE CORRECTION ANGLE.

Substituting equation (16) and (17) into equation (15) gives:

$$Sin(\gamma) = \frac{Cos(90-\lambda)}{Cos(\varepsilon)} \tag{18}$$

Using a trigonometric identity:

$$Cos(90^o - \lambda) = Sin(\lambda) \tag{19}$$

Substituting equation (19) back into equation (18) gives:

$$Sin(\gamma) = \frac{Sin(\lambda)}{Cos(\varepsilon)} \tag{20}$$

Equation (5) can now be rearranged by substituting equations (14) and (20) to give:

$$Tan(\Phi) = \frac{\dfrac{(R-r)Sin(\lambda)}{Cos(\varepsilon)}}{L \cdot Cos(\varepsilon) + (R-r) \cdot Cos(\gamma) \cdot Sin(\varepsilon)} \tag{21}$$

Using the trigonometric identities (22) and (23) then rearranging equation 21 gives:

$$Cos(\gamma) = \sqrt{1 - Sin^2(\gamma)} \tag{22}$$

$$Sin(\varepsilon) = \sqrt{1 - Cos^2(\varepsilon)} \tag{23}$$

$$Tan(\Phi) = \frac{Sin(\lambda)}{\dfrac{L \cdot Cos^2(\varepsilon)}{(R-r)} + Sin(\varepsilon) \cdot Cos(\varepsilon)\sqrt{1 - Sin^2\gamma}} \tag{24}$$

Equation (24) provides the Theodolite correction angle (Φ) as a function of cant angle (λ) and gun tube elevation (ε) by using known parameters R, r and L. If the gun tube has no tube taper, then equation (24) becomes:

$$Tan(\Phi) = \frac{Sin(\lambda)}{Sin(\varepsilon) \cdot Cos(\varepsilon)\sqrt{1 - Sin^2\gamma}} \tag{25}$$

APPENDIX E. REFERENCES.

1. MIL-STD-810G Environmental Engineering Considerations and Laboratory Tests, 31 October.

2. TOP 01-1-011, Vehicle Test Facilities at Aberdeen Proving Ground, 6 July 1981.

3. FM 6-50, Tactics, Techniques, and Procedures for the Field Artillery Cannon Battery.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: TEDT-YPY-MWA, 301 C Street, Yuma, AZ 85365. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.